Analysis on the Transmission Phase Response of the E-IT and M-IT Meta-structures

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Abstract — **The transmission phase response of the electrically induced transparency (E-IT) structure and magnetically induced transparency (M-IT) structure in free space are analyzed in this paper, respectively. Both E-IT and M-IT meta-structures have the maximum phase self-changing about 50^o at a fixed frequency. Interestingly, there is a 180^o phase-jump in M-IT meta-structure which leads to a total phase change about 180^o at any fixed frequency. The relative transmission amplitudes are within -1 dB. Such meta-structures are very useful for spacial electromagnetic wave tuning.**

Index terms — **Electrically induced transparency, magnetically induced transparency, transmission phase response, spacial electromagnetic wave tuning**

I.INTRODUCTION

The electromagnetically induced transparency (EMIT) effect is a coherent control technique to eliminate the opaque effect of a medium in a propagating beam of electromagnetic radiation. It usually leads to an extremely narrow transparency window over a wide absorption band [1]. The effect was demonstrated in optically opaque strontium vapor by K.-J. Boller et. al [2]. The EMIT effect was also observed in some other non-quantum structures, such as split ring resonators [3], coupled metal-strip antennas [4] and so on. In these EMIT structures, two eigen modes named as "bright" mode and "dark" mode were induced respectively. Generally, the bright mode exhibits a strong coupling to the radiation field, whereas the dark mode is excited by its coupling to the bright mode. Although the magnitude response of EMIT structure has widely been researched, the detailed transmission phase response in the passband has seldom been mentioned. In this paper, we present an electrically induced transparency (EIT) structure and magnetically induced transparency (MIT) structure in free space, respectively. The phase responses of these two structures are mainly discussed.

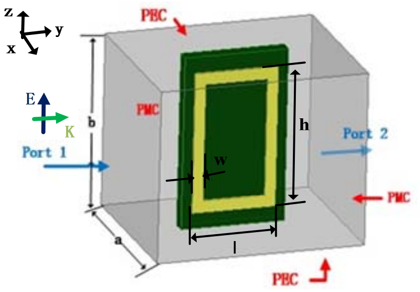
The transmission phase change around the resonant frequency of meta-structures has long been attracted by many researchers. The method of controlling the magnitude and phase of each element in the array individually by varying the element's dimensions is widely adopted to enhance the gain of the antenna, which is called multilayer frequency selective surfaces (M-FSS) [5]-[7]. According to [8], there exits transmission phase limits, which the maximum transmission phase ranges of multiple layers are constrained to certain degrees for 1-dB and 3-dB transmission coefficients. However, in those designs, the vector of the incident plane wave is normal to the layers, only electrical resonance is induce.

In this paper, the E-IT and M-IT structures are proposed parallel to the propagation direction of the incident plane wave. By slightly changing the central transmission band, the self-shifted phases of the E-IT structure and M-IT structures are both about 50^o. The detailed analysis is presented in Section II and some conclusions are presented in Section III.

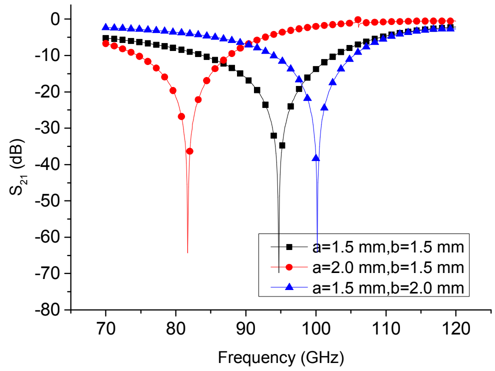
II. ANALYSIS AND SIMULATION RESULTS

A. Design and Analysis of the Single Electrical Resonance Element

We first give a rectangular ring with low Q-factor in the W-band, which corresponds to a wide absorption band. As shown in Fig.1, the substrate with relative permittivity of ε_r=2.2 and thickness of 0.127 mm is used. The rectangular ring, which is made of PEC (perfect electrical conductor) and the thickness of 0.018 mm, is etched on one side of the substrate. We set PEC and PMC boundaries to simulate the incident plane wave passing through the element. The vector of propagation k is parallel to the ring (Fig.1 (a)). The values of a and b, which decide the extent of space between two elements along y-direction and z-direction, definitely affect the performance of the rectangular ring when its size is fixed. Fig.1 (b) gives the effects of changing the value of a and b with fixed h=1.22 mm, w=0.1 mm and l=0.8 mm. When increasing a, the center frequency will go towards to lower frequency while by increasing b, the center frequency will go higher. In both situations, the absorption band will become narrower. Considering the bandwidth and the fabrication problem in W-band, we choose a=1.5 mm and b=1.5 mm. The center resonating frequency is 95 GHz. We then will observe the transmission phase change at this frequency.



(a)

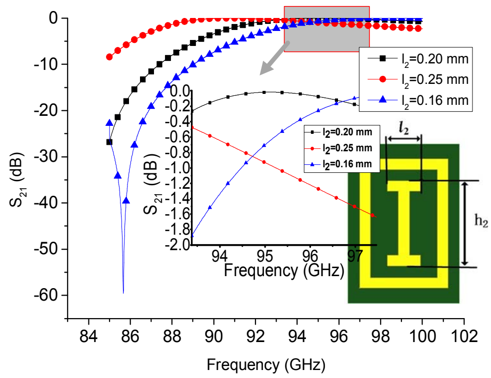


(b)

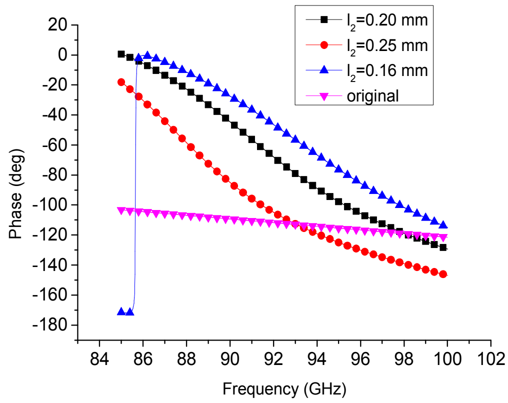
Fig.1 The schematic structure and effect of lengths a and b: (a) the structure of the rectangular ring resonator; (b) simulated results of changing the value of a and b (fixed h =1.22 mm, w=0.1 mm, l=0.8 mm).

B. Design and Analysis of the E-IT Meta-structure

The E-IT structure is integrated by an I-shape electrical resonator in the rectangular ring. The widths of all metal strips are 0.1 mm. The gap between the I-shape resonator and the rectangular ring is 0.11 mm. We fix the h_2=0.8 mm. Thus, by changing the value of l_2, the passband can be changed and the transmission phase at 95 GHz will be changed accordingly. We give three E-ITs with different l_2 as presented in Fig.3 (a). It shows that larger l_2 leads to lower E-IT frequency and narrower transparency band. The transmission phase responses of different EITs are given in Fig.3 (b). In comparison, we firstly put the blank substrate without any metal structures in order to acquire the original transmission phase response. Then, we put E-IT meta-structures on the substrate to observe the phase response in the passband and the maximum phase range at 95 GHz with -1 dB transmission coefficient is to be obtained. It can be seen from Fig.2 that in the passband of these EIT structures, the phase transmission line is always pass through the original phase transmission line, and the cross sections are just right at the center frequency of E-IT band, which means that there are no transmission phase effects of each EIT structure at these frequencies. The plane wave will transmit through the slabs just as if there is no things on the substrate however a little transmission loss. At 95 GHz, the maximum phase changing range we can get is about 50^o, from -125^o to -75^o under the 1-dB transmission coefficient restriction, which conforms the rules just as [9] mentioned.



(a)

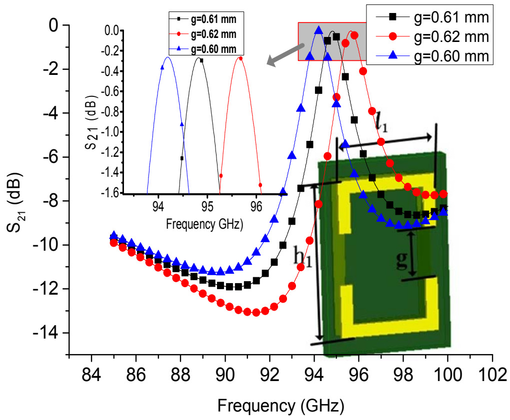


(b)

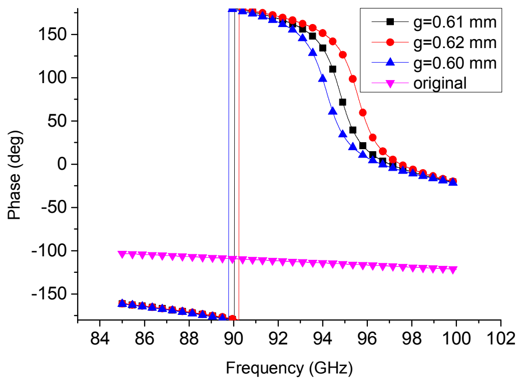
Fig.2 The E-IT meta-structure and transmission phase responses: (a) the E-IT meta-structure and transmission magnitude response, (b) transmission phase response.

C. Design and Analysis of the M-IT Meta-structure

The M-IT structure is putting the symmetric split ring resonator (SRR) hiding behind the rectangular ring (on the opposite of the substrate). The M-IT frequency band can be easily varied by tuning the gap width of g. The observation method we used here is the same as mentioned above. Three M-IT meta-structures with different values of g are given in Fig.4. From Fig.4 (a), we see that the performance of MIT structure is totally different from EIT structure. The transmission bandwidth of the M-IT structure is very narrow corresponding to a sharp change of the phase. There is a 180^o phase-jump in M-IT meta-structure below the passband and the transmission phase line is not pass though the original one again. The self-change of the phase is still about 50^o. But, affected by the phase jump, the phase difference between the M-IT passband and original all-passband is about 180^o at any fixed frequency as well as 95 GHz. In a word, if the E-IT and M-IT meta-structures are well combined and flat transmission from the E-IT and M-IT pass band is obtained. The total phase change of 180^o can be achieved which is very helpful in transmit array design to tune the spacial electromagnetic wave propagation.



(a)



(b)

Fig.3 The M-IT structure and transmission phase responses: (a) the EIT structure and transmission magnitude response, (b) transmission phase response.

III. CONCLUSION

In this paper, we analyze on the transmission phase responses of the E-IT and M-IT meta-structures. Through simulating E-IT and M-IT structure respectively, we find that the E-IT and M-IT structures have both self-change of the maximum transmission phase about 50^{o} at any fixed frequency. The M-IT meta-structure has another additional phase-jump which leads to a total phase change of about 180^{o} at the same frequency. Both conclusions are drawn under the condition of the 1-dB transmission loss in the passband. An EMIT meta-structure is hope to be achieved by combining such two meta-structures and the range of phase change can be tuned continuously in a maximum range of 180^{o}.

ACKNOWLEDGEMENT

This work was supported in part by the Program for New Century Excellent Talents in University under Grant No. NECT-13-0095, in part by the Fundamental Research Funds for the Central Universities under Grant No. ZYGX2014J016, in part by the Scientific Research Foundation for the Returned Overseas Chinese Scholars, State Education Ministry, and in part by the State Key Laboratory of CEMEE Foundation under Grant No. CEMEE2015K0201B.

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